NOAA EXPERIMENTAL DIVING UNIT
REPORT 92-2

APPLICATIONS OF VORTEX TUBE TECHNOLOGY in the COOLING of RECOMPRESSION CHAMBER ATMOSPHERES I

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DIVING PROGRAM

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INTRODUCTION

NOAA Experimental Diving Report 92-1, "Potential Applications of Vortex Tube Technology in the Cooling, Dehumidification and Heating of Hyperbaric Environments" (1) included data which demonstrates that vortex tubes function effectively under hyperbaric conditions, and suggested that they are of potential use in hyperbaric environmental control, diving, and support systems and activities. This report addresses the use of vortex tubes in the cooling of recompression chamber atmospheres.

MATERIALS and METHODS

A schematic of the vortex tube as modified for these experiments is shown in figure 1. The unit is mounted inside the recompression chamber. Air is supplied from the chamber BIBS at a differential pressure of 100 psi to the vortex generator. This air is diverted into an outer spiral down the barrel. A portion of this outer spiraling air exhausts at the end of the barrel through an adjustable valve, and the remainder is diverted into an inner spiral, traveling toward the opposite end of the barrel. Heat is transferred from the inner spiral to the outer spiral. A portion of this heat is eliminated with the exhaust air, and a portion warms the metal barrel. The inner (cold) spiral of air exits the opposite end of the apparatus into the chamber atmosphere. To eliminate the heat given off by the metal barrel, a cooling duct was installed around the barrel. A volume of air from the chamber, equal to that of the cold air fraction, passes through the cooling duct and is exhausted from the chamber with the hot air fraction of the vortex apparatus. The hot components of the system are insulated to prevent heat dissipation into the chamber.

A schematic of the apparatus and accessories is shown in figure 2. This vortex tube with the modifications was tested in a recompression chamber on the surface and at 60 feet of seawater (fsw), a common treatment depth. Temperatures were taken of the air inside the chamber (labeled AIR on the graphs) and on the outside of the chamber surface (labeled A, B, and D on the graphs). The locations of the temperature readings on the hull are displayed in figure 3. The chamber surface temperature probes were insulated on the outside to provide more accurate hull temperature measurements. Hull and inside air temperatures were recorded on a strip chart recorder. Vortex apparatus supply pressure and cold air temperature were measured with a pressure gauge and thermometer visible through the chamber port. A standard NOAA 42 inch, double-lock, portable recompression chamber was used for the tests, which were conducted in the diving facility at the Virginia Institute of Marine Science. Ambient air temperature in the facility was maintained at 25.5°C.

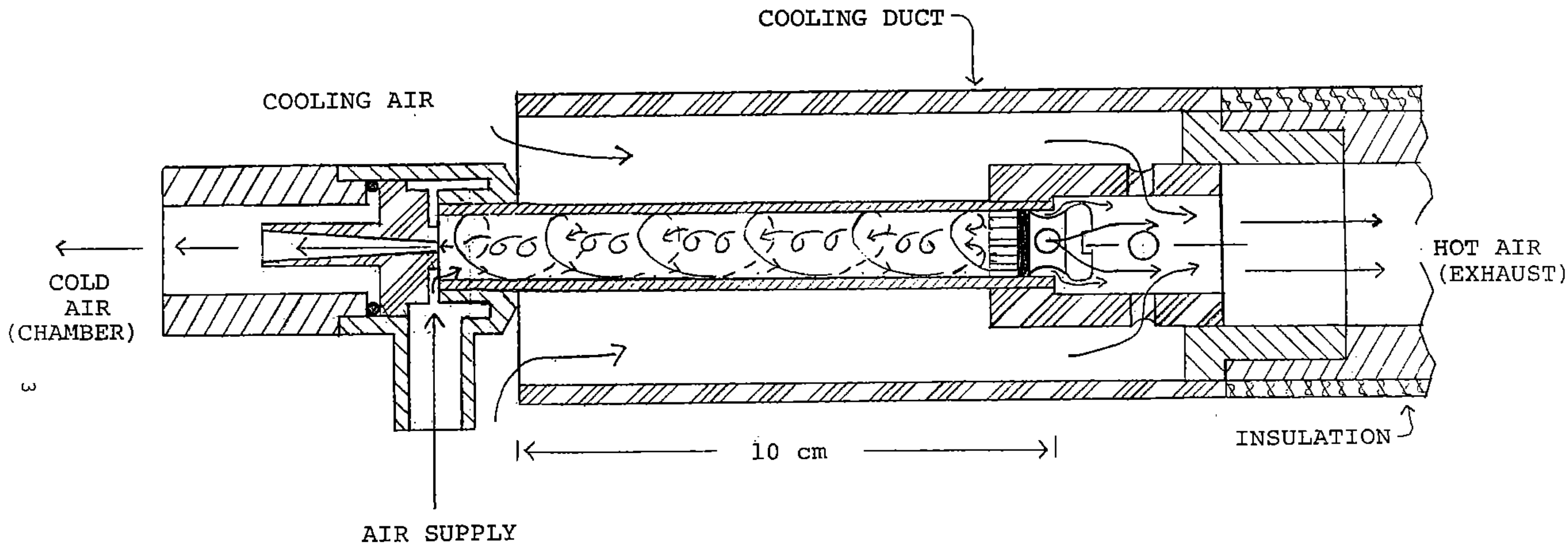

COOLING DUCT
COOLING AIR
COLD
AIR
(CHAMBER)
HOT AIR
(EXHAUST)
10 cm
INSULATION
AIR SUPPLY

Figure 1

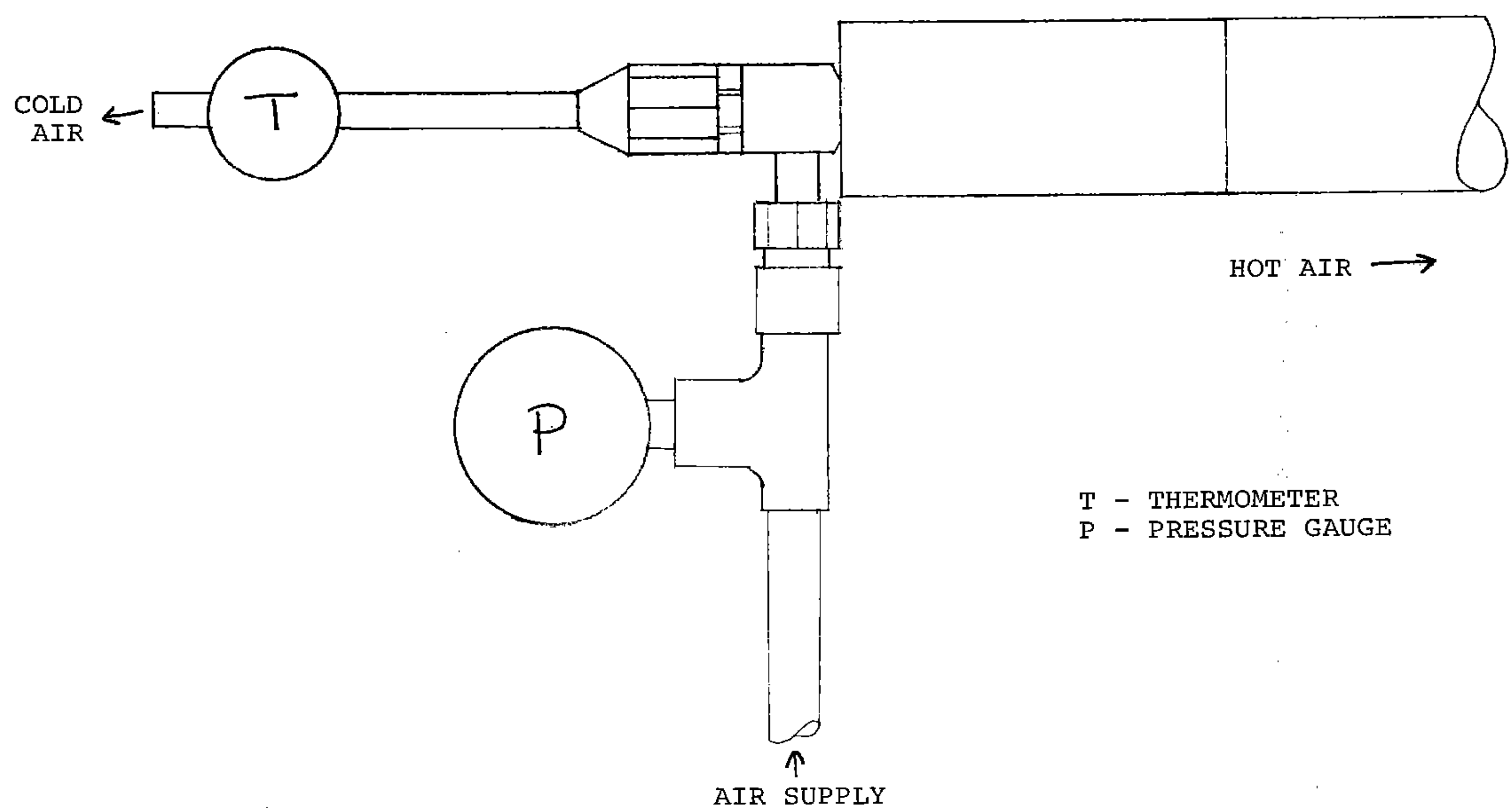
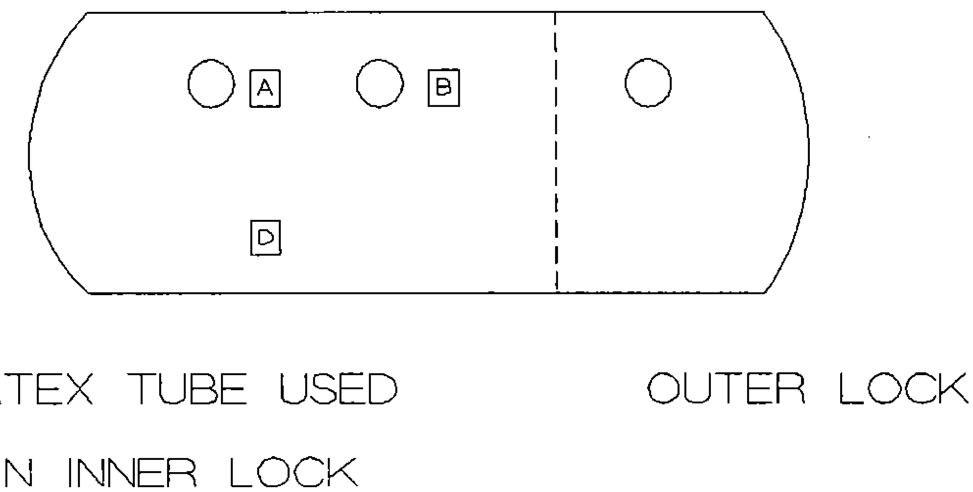

COLD AIR
T
HOT AIR
P
T - THERMOMETER
P - PRESSURE GAUGE
AIR SUPPLY

Figure 2

LOCATION OF TEMPERATURE READINGS ON CHAMBER HULL



(NOT TO SCALE)

Figure 3

The vortex apparatus was adjusted to a cold air temperature of -4.4°C and a hot air temperature of 45°C. A differential pressure of 100 psi was maintained between the air supply and chamber atmosphere by an external regulator. Manufacturers specifications state that these settings should provide cooling of approximately 1,000 Btu/hr at atmospheric pressure.

The air supply for the vortex tube and ventilation of the chamber came from a high pressure source. Some cooling of the air used in both situations occurred due to the Joule-Thomson effect.

Equipment specifications are listed at the end of this report.

RESULTS

Tests were conducted under four sets of conditions, and the results are shown in figures 4 through 7 (conditions 4-7). In all cases, chamber hull and air temperatures are plotted against time.

Condition 4 was conducted with the chamber at atmospheric pressure. The vortex apparatus was turned on, kept on for 35 minutes and turned off. Within 5 minutes a stable air-hull temperature differential (▲T) was established at 2.0°C and maintained until the apparatus was turned off, and the ▲T returned to 0. A very small drop in both air and hull temperatures was recorded during the test.

Condition 5 consisted of a 1.67 minute compression to a pressure of 60 fsw. Pressure was maintained by air addition until the ▲T returned to "0". The vortex apparatus was turned on until a stable ▲T was attained (2.5°C), then turned off, and the chamber pressure reduced to atmospheric pressure.

Condition 6 consisted of a 1.67 minute compression to 60 fsw. The vortex apparatus was turned on at arrival at 60 fsw and kept on until the chamber pressure was reduced to atmospheric pressure. The ▲T recorded was 2.5°C.

Condition 7 consisted of a 1.83 minute compression to 60 fsw. A 5 minute, 62 standard cubic feet per minute (scfm) vent was initiated on arrival at 60 fsw, followed by 1 minute vents separated by 5 minute intervals. After 30 minutes the vortex apparatus was turned on until a stable 2.5°C ▲T was obtained.

Initial heating and final cooling of the chamber air in figures 5, 6, and 7 were caused by compression and decompression.

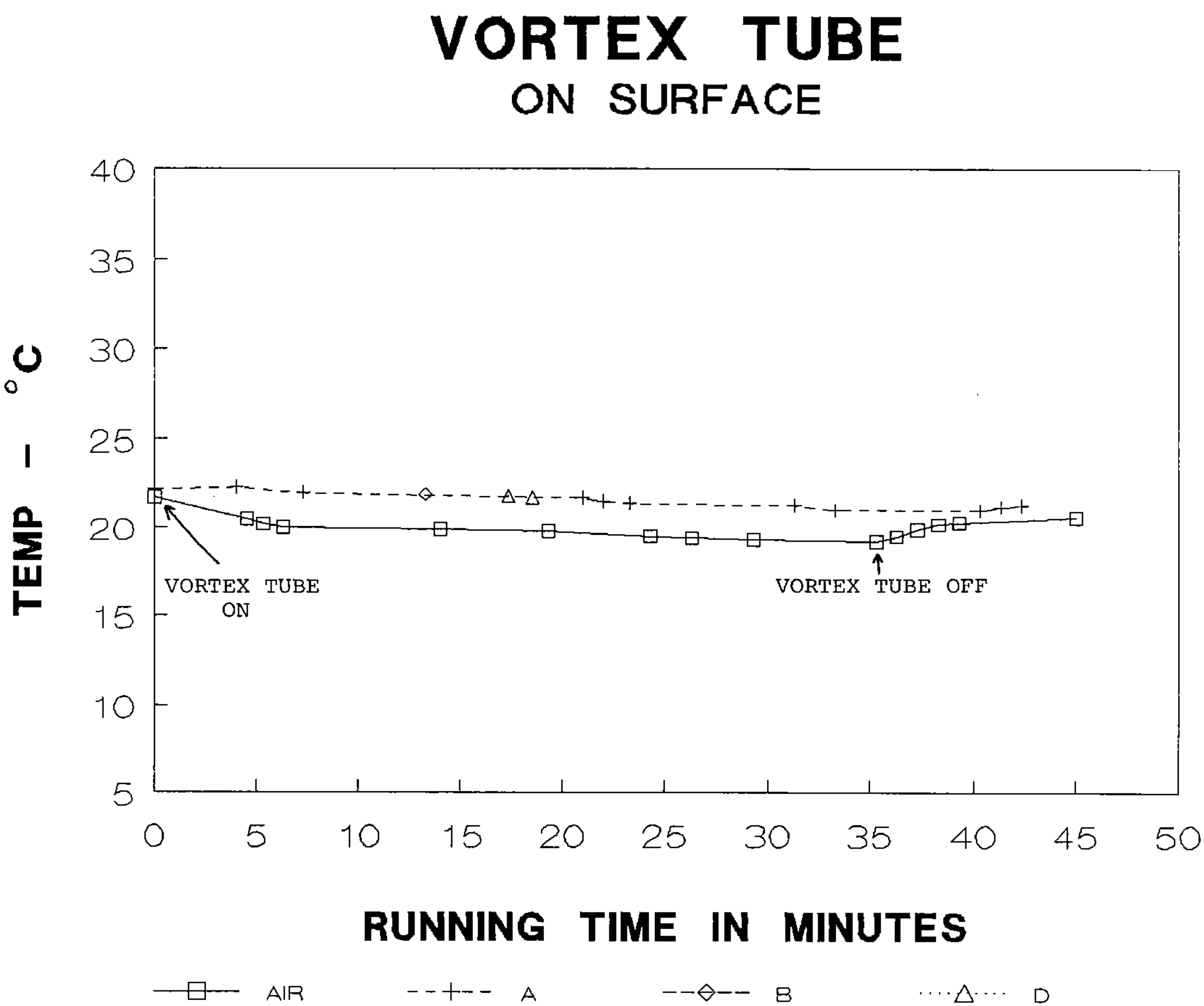

VORTEX TUBE
ON SURFACE
TEMP - °C
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
VORTEX TUBE
ON
VORTEX TUBE OFF
RUNNING TIME IN MINUTES
AIR
A
B
D

Figure 4

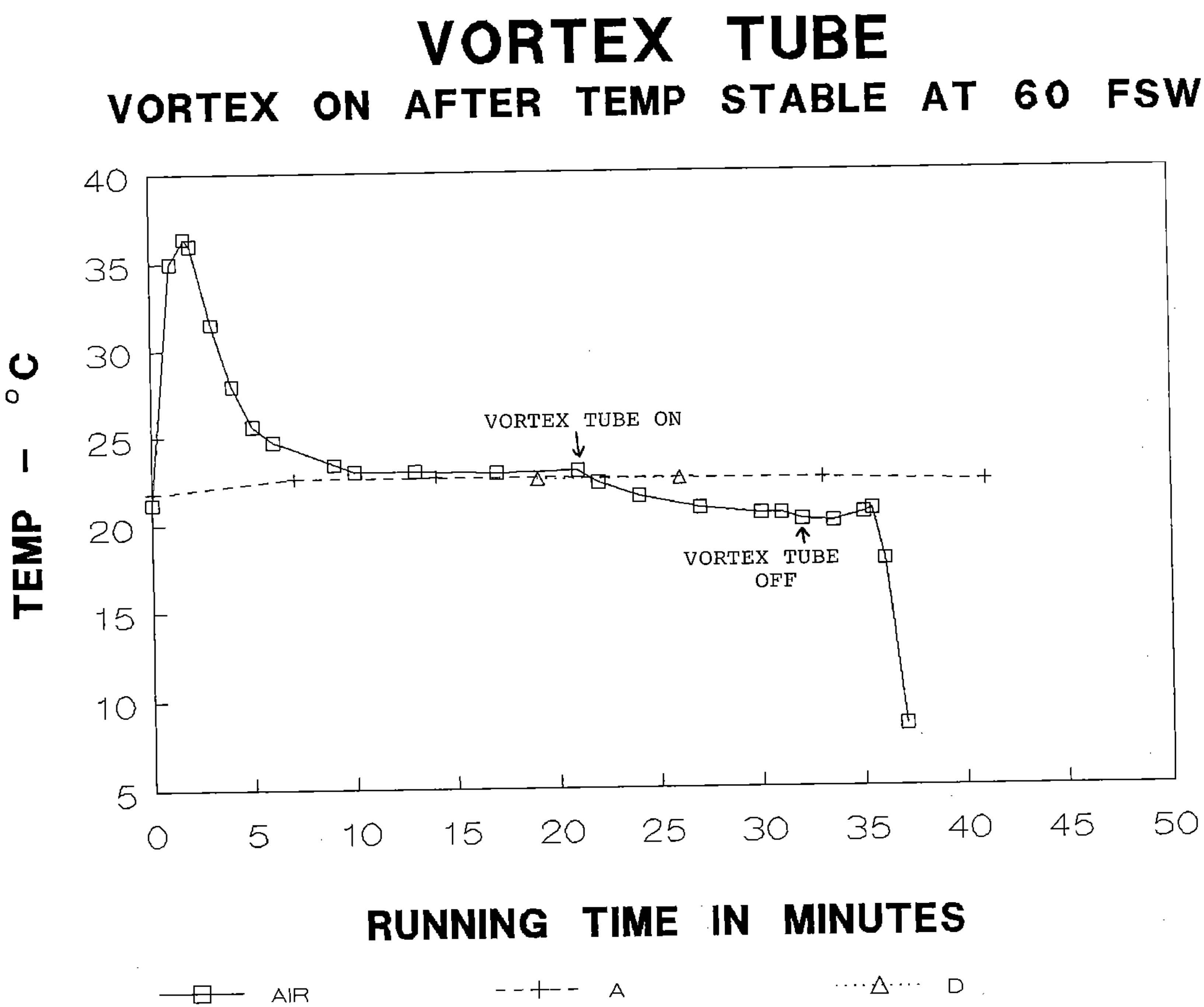

VORTEX TUBE
VORTEX ON AFTER TEMP STABLE AT 60 FSW
TEMP - °C
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
VORTEX TUBE ON
VORTEX TUBE OFF
RUNNING TIME IN MINUTES
AIR
A
D

Figure 5

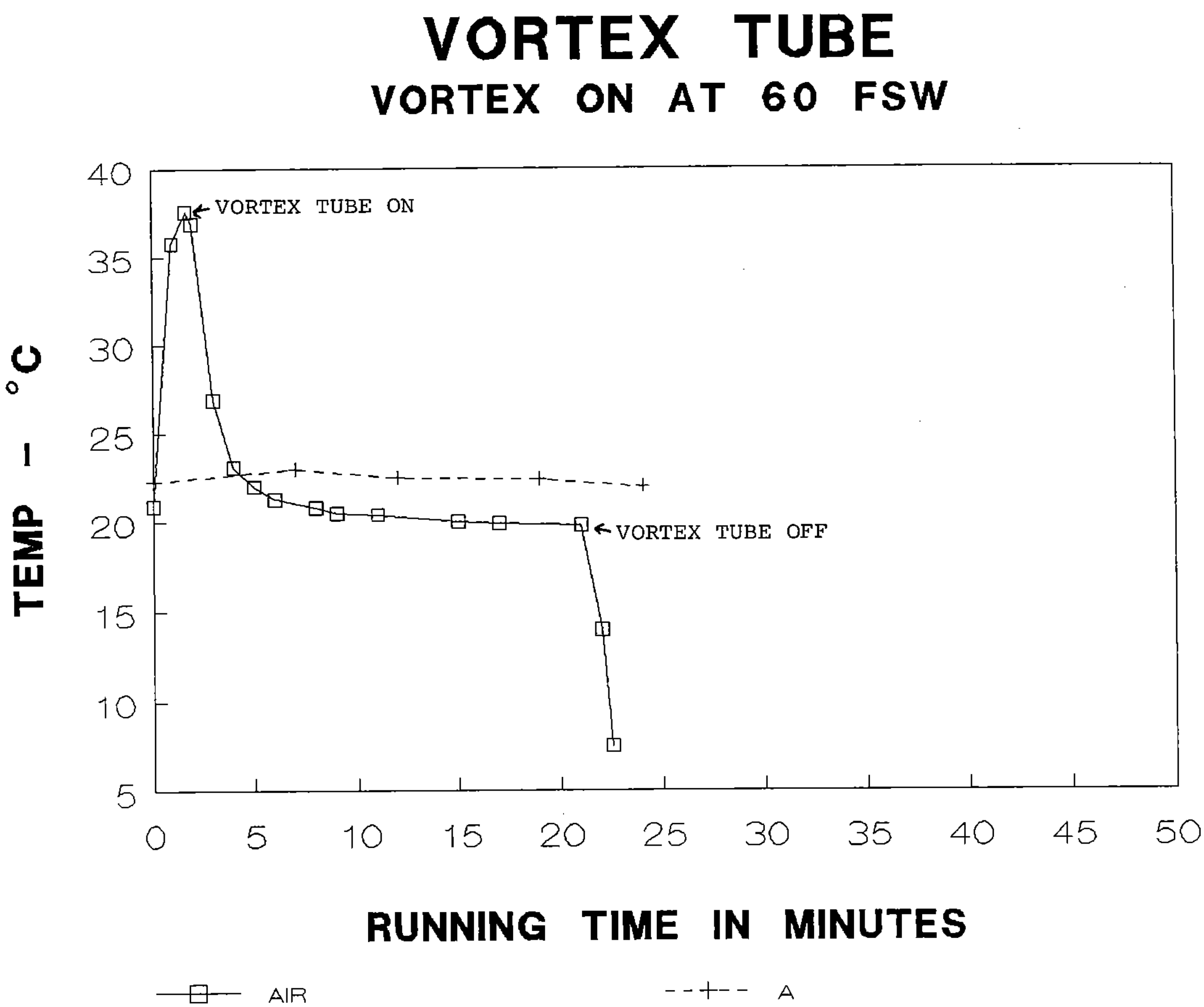

VORTEX TUBE
VORTEX ON AT 60 FSW
VORTEX TUBE ON
VORTEX TUBE OFF
TEMP - °C
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
RUNNING TIME IN MINUTES
AIR
A

Figure 6

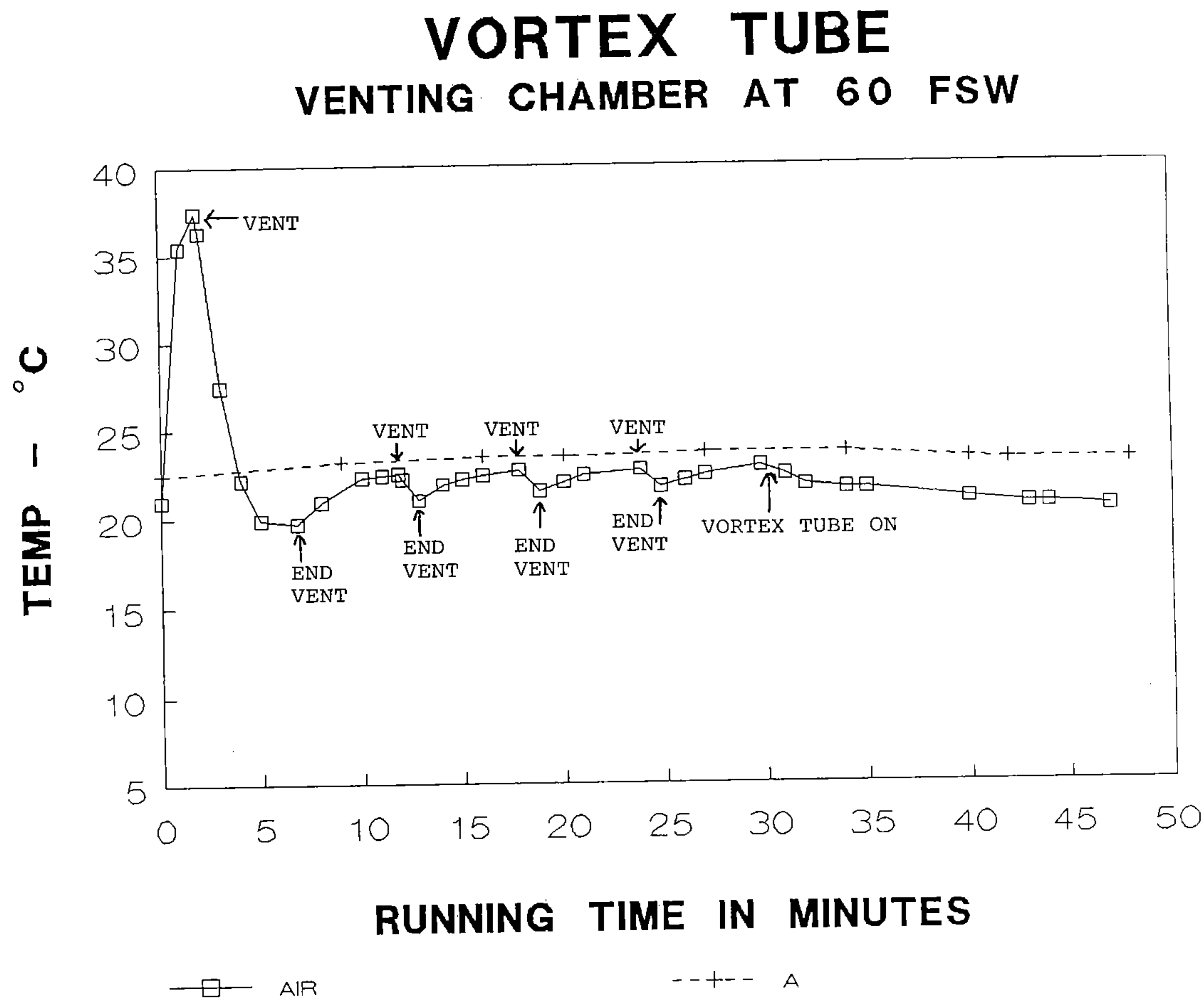
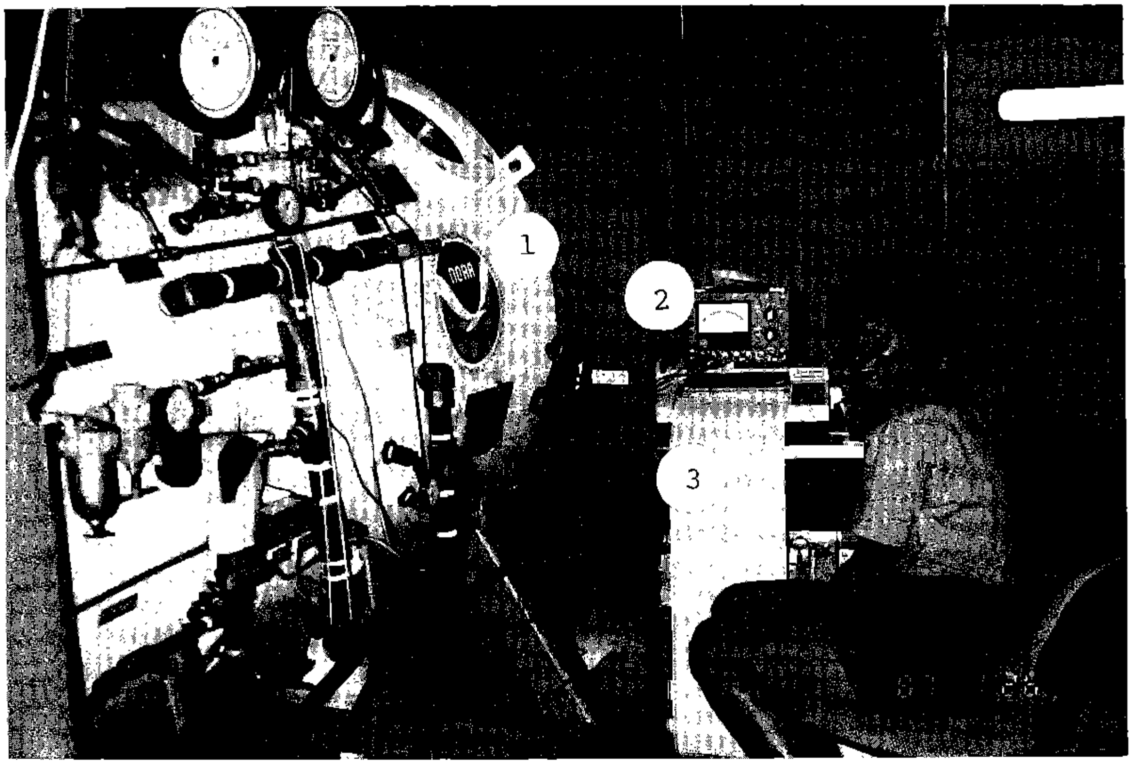
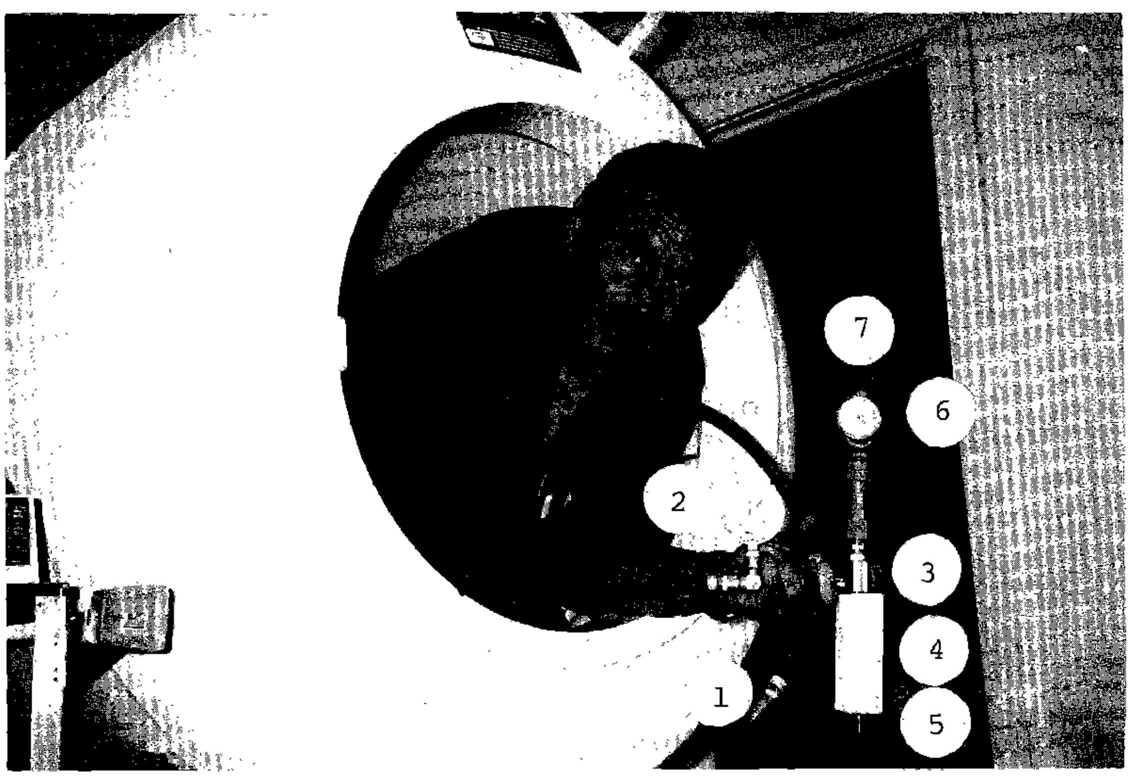

VORTEX TUBE
VENTING CHAMBER AT 60 FSW
TEMP - °C
40
35
30
25
20
15
10
5
0
5
10
15
20
25
30
35
40
45
50
VENT
VENT
VENT
VENT
END VENT
END VENT
END VENT
END VENT
VORTEX TUBE ON
RUNNING TIME IN MINUTES
AIR
A

Figure 7



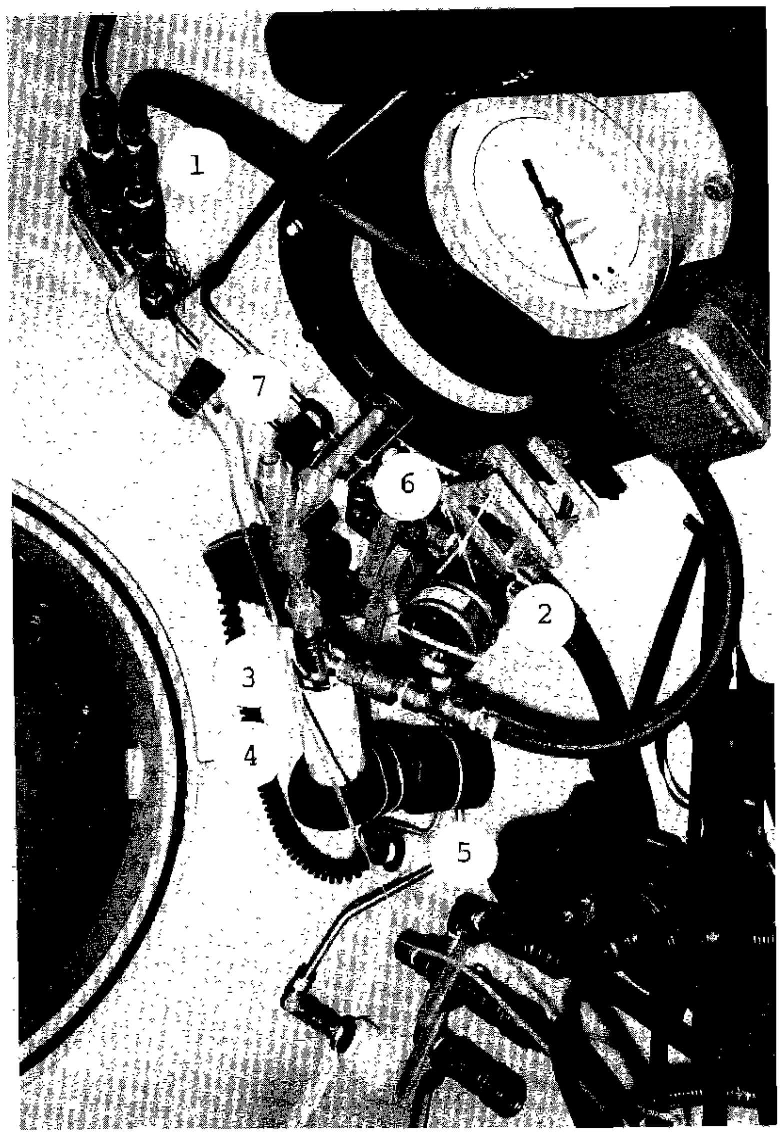
1. NOAA 42" Double-Lock Portable Recompression Chamber
2. YSI Tele-Thermometer, Model 46TUC
3. Microscribe Strip Chart Recorder, Model 4520

Figure 8



1. Inlet Hose
2. Pressure Gauge
3. EXAIR Vortex Tube
4. Cooling Duct
5. Hot Air Exhaust
6. Dial Thermometer
7. Cold Air Outlet

Figure 9 - 19



1. Inlet Air Supply
2. Pressure Gauge
3. Vortex Tube
4. Cooling Duct
5. Hot Air Exhaust
6. Dial Thermometer
7. Cold Air Outlet

Figure 10

DISCUSSION

This study demonstrated that small, simple vortex tube technology can:

1. Function under commonly used hyperbaric conditions;
2. Provide more effective recompression chamber cooling than air ventilation at air consumption rates comparable to normal open-circuit chamber ventilation rates;
3. Provide chamber ventilation for CO2, O2, water vapor, and odor removal equivalent to conventional air ventilation at similar air consumption rates; and,
4. Maintain a 2.5°C air-hull temperature differential with a net hull and air temperature decrease of approximately .5°C/hr.

The above were accomplished at a cooling rate of less than half of the rated atmospheric pressure level. The value of 15 scfm was selected because it is comparable to normal chamber ventilation rates at 60 fsw. Manufacturers cooling specifications (2) are listed below.

SCFM	Btu/hr
10	650
15	1000
25	1700
30	2000
40	2800

This study suggests that this technology has further applications in the following areas:

1. Increased cooling capacity at higher air consumption rates;
2. Pre-cooling and real-time cooling of the chamber hull and air for surface decompression operations and recompression therapy;
3. Whole or partial body cooling of individuals by routing cooling air through appropriate hoods or clothing.

All of the above are currently being addressed at the NOAA EDU.

EQUIPMENT SPECIFICATIONS

1. YSI Tele-Thermometer, Model 46TUC, 6 Probe, 5 Range, °C
2. YSI Thermesters, Probe 409B Attachable Surface Temperature, Time constant - 1.1 sec, maximum temperature - 100°C
3. Microscribe Strip Chart Recorder, Model 4520, Dual Pen, operated at 100mv and 60 cm/hr
4. Standard NOAA 42" Double-Lock, Steel, Portable Recompression Chamber, 100 psi, 3000 lbs.
5. EXAIR Vortex Tube, Model 3215, Generator R-15, 15 SCFM, 100 psig.

ACKNOWLEDGMENTS

1. Virginia Institute of Marine Science, Daniel V. Gouge, Diving Safety Officer, Gloucester Point, VA - facility and technical support

2. U.S. Army Transportation Center, Ft. Eustis, VA - facility support

3. NOAA Officer Training Center, Ft. Eustis, VA - facility support

4. Gloucester Supply, Inc., Gloucester, VA - assistance on component selection

REFERENCES

1. Wells JM, Campbell WB. Potential applications of vortex tube technology in the cooling, dehumidification and heating of hyperbaric environments. NOAA Experimental Diving Unit Report 92-1.

2. EXAIR Corporation, Catalog No. 91, 1250 Century Circle North, Cincinnati, Ohio 45246-3309.

NOAA EXPERIMENTAL DIVING UNIT
CONVERSION TABLE

Temperature

°F = (1.8 x °C) + 32
°R = °F + 459.67

°C = 5/9 x (°F - 32)
K = °C + 273.15

Pressure (Depth)

1 Atmosphere	=	33 Feet Sea Water
1 Atmosphere	=	10.1 Meters Sea Water
1 Atmosphere	=	14.7 Pounds/Square Inch
1 Atmosphere	=	101.325 kPa
1 Foot Sea Water	=	0.030 Atmospheres
1 Foot Sea Water	=	0.3048 Meters Sea Water
1 Foot Sea Water	=	0.445 Pound/Square Inch
1 Foot Sea Water	=	3.063 kPa
1 Meter Sea Water	=	0.099 Atmospheres
1 Meter Sea Water	=	3.28 Feet Sea Water
1 Meter Sea Water	=	1.45 Pound/Square Inch
1 Meter Sea Water	=	10.0 kPa
1 Pound/Square Inch	=	0.068 Atmospheres
1 Pound/Square Inch	=	2.25 Feet Sea Water
1 Pound/Square Inch	=	0.68 Meters Sea Water
1 Pound/Square Inch	=	6.8965 kPa
1 kPa	=	0.009869 Atmospheres
1 kPa	=	0.326 Feet Sea Water
1 kPa	=	0.1 Meters Sea Water
1 kPa	=	0.145 Pound/Square Inch

Volume

1 Cubic Foot	=	28.32 Liters
1 Cubic Foot	=	0.028 Cubic Meters
1 Cubic Foot	=	7.48 Gallons
1 Liter	=	0.035 Cubic Feet
1 Liter	=	0.001 Cubic Meters
1 Liter	=	0.264 Gallons
1 Cubic Meter	=	35.31 Cubic Feet
1 Cubic Meter	=	1000 Liters
1 Cubic Meter	=	264.2 Gallons
1 Gallon	=	0.13 Cubic Feet
1 Gallon	=	3.79 Liters
1 Gallon	=	0.0038 Cubic Meters

NOAA EXPERIMENTAL DIVING UNIT
METRIC PREFIXES

Prefix	Symbols	Number
Peta-	P	x 10^{15}
Tera-	T	x 10^{12}
Giga-	G	x 10^{9}
Mega-	M	x 10^{6}
Kilo-	k	x 10^{3}
Hecto-	h	x 10^{2}
Deka-	da	x 10^{1}
Deci-	d	x 10^{-1}
Centi-	c	x 10^{-2}
Milli-	m	x 10^{-3}
Micro-	μ	x 10^{-6}
Nano-	n	x 10^{-9}
Pico-	p	x 10^{-12}
Femto-	f	x 10^{-15}